Vector meson production with hadron beams at Compass

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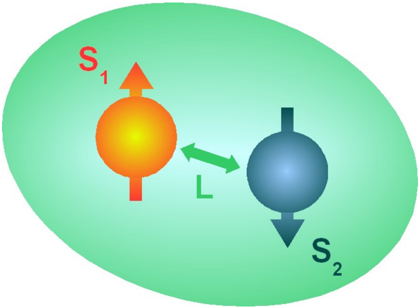
Outline

Quark model

Mesons

- Simplified meson model: $q\bar{q}$ bound states
- characterized by
  1. Flavour (u,d,s,c,b,t)
  2. Quantum numbers $I^G J^{PC}$



Quantum numbers and symmetries

Quantum numbers

- Spin $\vec{S} = \vec{S}_1 + \vec{S}_2$
- Angular momentum $\vec{J} = \vec{L} + \vec{S}$
- Isospin $\vec{I}, I_3 = \pm\frac{1}{2}$ (for u/d quark content)
- Parity $\widehat{P}\ \Psi(\vec{r}) = \Psi(-\vec{r})$
- $P = (-1)^{L+1}$ with $L = |\vec{L}|$
- Charge conjugation $\widehat{C}\ \Psi(q) = \pm\Psi(-q)$ (odd/even)
- $C = (-1)^{L+S}$ with $S = |\vec{S}|$
- G-parity $\widehat{G} = \widehat{C} e^{i\pi I_2}$
- $G = C\ (-1)^I = (-1)^{L+S+I}$

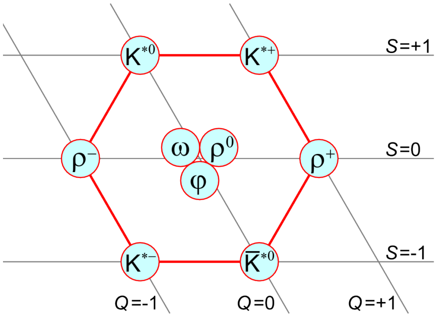
All of these quantum numbers are conserved in strong interactions.

allowed J^{PC} combinations: 0^{-+},0^{++},1^{--},...

Light vector mesons

Vector mesons: $J^P = 1^-$

Light mesons with flavours u, d, s fulfill $SU(3)$ symmetry quite well ($m_u \simeq m_d \simeq \mathcal{O}(m_s)$), thus a light $q\bar{q}$ state can be made out of $3 \otimes 3 = 8 \oplus 1$ combinations:



Light vector mesons cntd.

No differences in mass would lead to the states

$$\omega_1 = \frac{1}{\sqrt{3}}(u\bar{u} + d\bar{d} + s\bar{s})$$

$$\omega_8 = \frac{1}{\sqrt{3}}(u\bar{u} + d\bar{d} + s\bar{s})$$

while due to small mass differences "ideal" mixing occurs

$$\begin{pmatrix} \phi \\ \omega \end{pmatrix} = \begin{pmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{pmatrix} \begin{pmatrix} \omega_1 \\ \omega_8 \end{pmatrix}$$

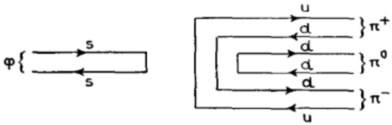
leading to a pure $s\bar{s}$ state (ϕ) and the $\omega = \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})$ with an mixing angle of $\theta = 35.26^\circ$

Reality: deviation from ideal mixing is only $\delta\theta = 3.7^\circ$

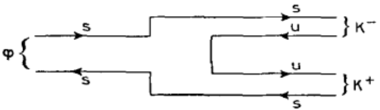
OZI rule

Decay of vector mesons

Model: **O**kubo-**Z**weig-**I**izuka rule[2]: decay processes with disconnected quark lines suppressed



OZI forbidden



OZI allowed

[2]S. Okubo, Phys. Lett. 5 (1963) 165, G. Zweig, CERN report TH-401 (1964), J. Iizuka, Prog. Theor. Suppl. 38 (1966) 21

OZI rule cntd.

Observed branching ratios confirm validity of OZI rule:

ϕ(1020) $I^G(J^{PC}) = 0^-(1^{--})$

Mass $m = 1019.455 \pm 0.020$ MeV (S = 1.1)
Full width $\Gamma = 4.26 \pm 0.04$ MeV (S = 1.4)

ϕ(1020) DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)
K^+K^-	(48.9 ±0.5) %	S=1.1	127
$K^0_L K^0_S$	(34.2 ±0.4) %	S=1.1	110
$\rho\pi + \pi^+\pi^-\pi^0$	(15.32 ±0.32) %	S=1.1	–

Violations of the OZI rule

Prediction[3] for $\phi(1020)$ to $\omega(782)$ decay ratios:

$$\sigma(AB \to \phi X)/\sigma(AB \to \omega X) = 4.2 \times 10^{-3}$$

with A and B hadrons

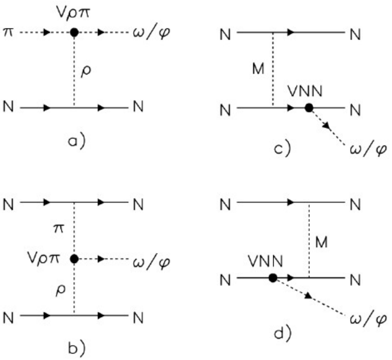
Numerous violations observed, possible explanations:

- reactions on nucleons: strangeness content of the nucleon enhances $s\bar{s}$ production
- intermediate (gluon-rich) states
- production mechanisms different (here: $\phi(1020)$ and $\omega(782)$ production)

[3] H.J. Lipkin, Phys. Lett. B 60 (1976) 371

Production mechanisms

Relevant processes[4]:



a) diffractive dissociation (here: vector meson exchange)
b) central production (here: double reggeon exchange)
c) FSI / rescattering / Deck effect
d) ISI / Deck effect
e) charge exchange (not depicted)

[4] A. Sibirtsev and W. Cassing, Eur. Phys. J. A 7 (2000) 407

Production mechanisms / spin alignment

How was the vector meson produced?
Spin alignment[2] helps: spin state of a particle[3]

$$\phi_i = \sum_n c_n^i \chi_n$$

with a corresponding spin-density matrix

$$\rho_{ij} = \sum_n w_i \; {}^n c_i^* \; {}^n c_j$$

with a weight w_i of each eigenstate χ_n

Spin 1 particles $\Rightarrow dim(\rho) = 2J + 1 = 3$

[2] K. Gottfried, J.D. Jackson, Nouvo Cim. 33 (1964) 302

[3] K. Schönning, Meson Production in pd Collisions, Uppsala Dissertations from the Faculty of Science and Technology 84, 2009 and references within

Spin alignment cntd.

Characteristics of ρ:

- Hermeticity $\rho^\dagger = \rho$
- Positive semi-definite: $Tr\{\rho\} \leq 1,\ Tr\{\rho^2\} = 1$
- symmetric: $\rho_{ij} = \rho_{ji}$

which also gives in combination $Tr\{\rho\} = 1 = \rho_{00} + 2\rho_{11}$.
Thus, the differential cross section becomes th following dependency[4]

$$\frac{d\sigma}{d\Omega} \propto \rho_{11}\ \sin^2(\theta) + \rho_{00}\ \cos(\theta) - \sqrt{2}\rho_{10}\ \cos(\phi)\ \sin(2\theta) - \rho_{-11}\ \cos(2\phi)\ \sin^2(\theta)$$

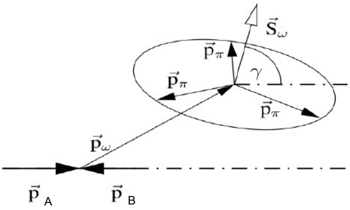
[4] K. Schilling, P. Seyboth and G. Wolf, Nucl. Phys. B 15 (1969) 397

Spin alignment cntd.

For unpolarized beam and target ⇒ independent of ϕ

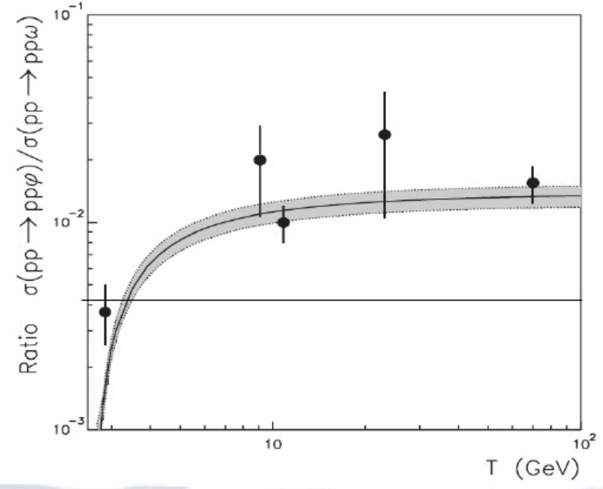
$$\frac{d\sigma}{d\cos(\theta)} \propto \rho_{11}\ \sin^2(\theta) + \rho_{00}\ \cos(\theta)$$

Reference frame *e.g.* helicity frame ($\theta \equiv \gamma$):



Measurements

Spin alignment / production mechanism dependency of OZI violation manifests in energy dependency, as well:



Measurements cntd.

No OZI violation seen in

- pp annihilations in flight
- π induced reactions

violation (factor 5-20)

- pp annihilations at rest (initial state $^3S_1$)
- reactions with NN initial state
- reactions near kinematic threshold

Overview of relatively recent results to be found in V.P. Nomokonov, M.G. Sapozhnikov, Particles and Nuclei 24 (2003) 184

Amplitude analysis

Details on amplitude analysis *cf.* Promme's talk next week

Possible reaction at Compass $\pi^- \; p \; \rightarrow \; \pi^- \; \pi^0 \; \pi^+ \; \pi^- \; p$ to search for ω and its background. Possible waves:

J^{PC}	M^ϵ	L_1	Iso_1	L_2	Iso_2
0^{-+}	0^+	2	a_1^0/π^-	2	$\rho^-\pi^+$
0^{-+}	0^+	2	a_1^-/π^0	2	$\rho^0\pi^-$
1^{--}	0^-	0	a_1^0/π^-	0	$\rho^-\pi^+$
1^{--}	0^-	0	a_1^-/π^0	0	$\rho^0\pi^-$
1^{--}	0^-	2	a_1^0/π^+	0	$\rho^-\pi^+$
1^{--}	0^-	2	a_1^-/π^0	0	$\rho^0\pi^-$
1^{--}	0^-	2	a_2^0/π^+	2	$\rho^-\pi^+$
1^{--}	0^-	2	a_2^-/π^0	2	$\rho^0\pi^-$
2^{+-}	0^-	1	a_1^0/π^+	0	$\rho^-\pi^+$
2^{+-}	0^-	1	a_1^-/π^0	0	$\rho^0\pi^-$
2^{+-}	0^-	1	a_2^0/π^+	2	$\rho^-\pi^+$
2^{+-}	0^-	1	a_2^-/π^0	2	$\rho^0\pi^-$
3^{--}	0^-	2	a_1^0/π^+	0	$\rho^-\pi^+$
3^{--}	0^-	2	a_1^-/π^0	0	$\rho^0\pi^-$
3^{--}	0^-	2	a_2^0/π^+	2	$\rho^-\pi^+$
3^{--}	0^-	2	a_2^-/π^0	2	$\rho^0\pi^-$

Amplitude analysis / outlook

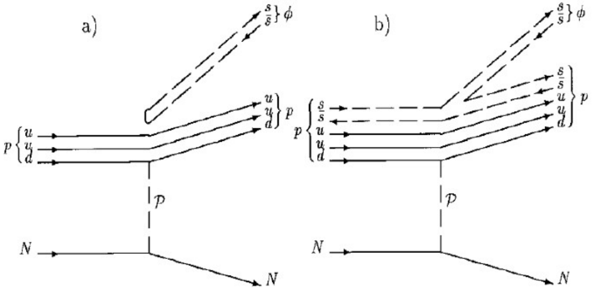
- results from BNL852, same PWA fitter available (maintained by S.Neubert/TUM)
- can be used for background estimation (interfering background)
- *per se* interesting

Necessary steps for the analysis:

- angular distributions
- acceptance corrections
- $\phi \rightarrow K\bar{K}$ analysis for OZI violation
- use different beams (π, p)

Outlook cntd.

$p\ p$ reactions violate OZI, $\pi\ p$ apparently not
hidden strangeness?



explanation by Sphinx[5], we can study with the same setup and trigger

[5] Sphinx collaboration, ZPA 359 (1997) 435

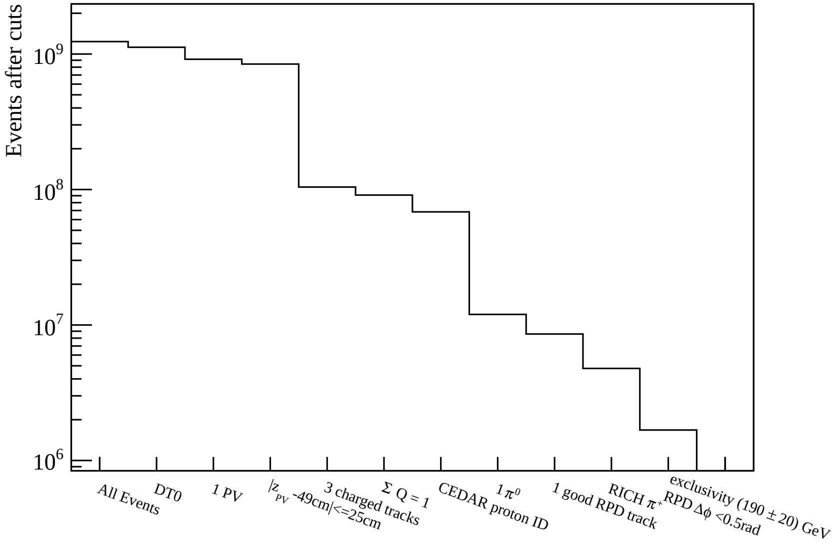
SPARES

Cuts

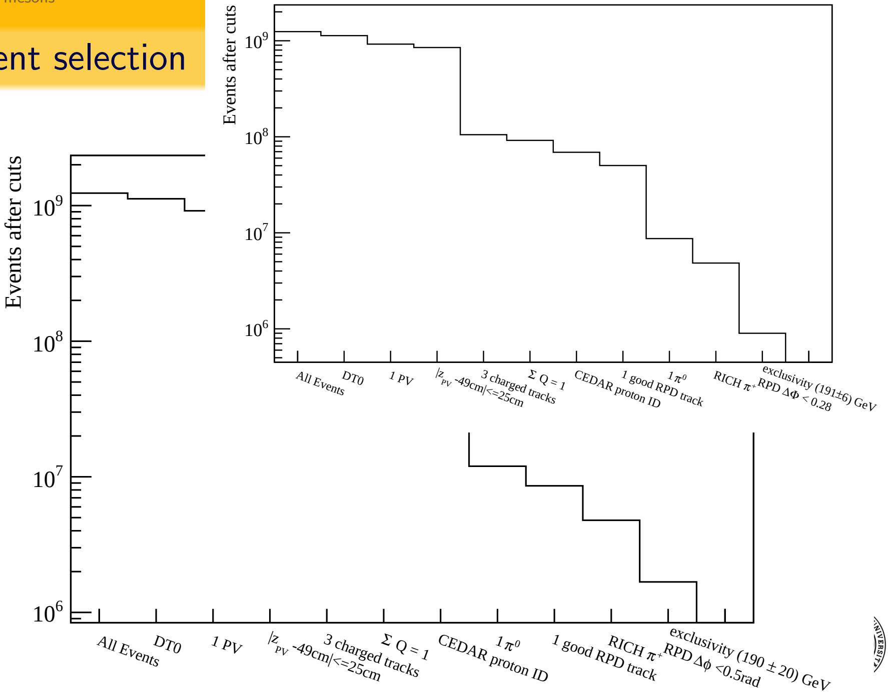
- DT0 trigger
- one primary vertex in target volume (z coord.)
- three charged outgoing tracks
- charge conservation
- CEDAR mult. > 4
- RPD track
- one π^0 candidate (γ energies rescaled, cut $\pm$ 7 MeV)
- RICH identifies π^+
- exclusivity (energy balance 192 GeV $\pm$ 6 GeV)
- coplanarity $|\Delta\Phi| < 0.28$

All cuts correspond to $\pm$ 2σ

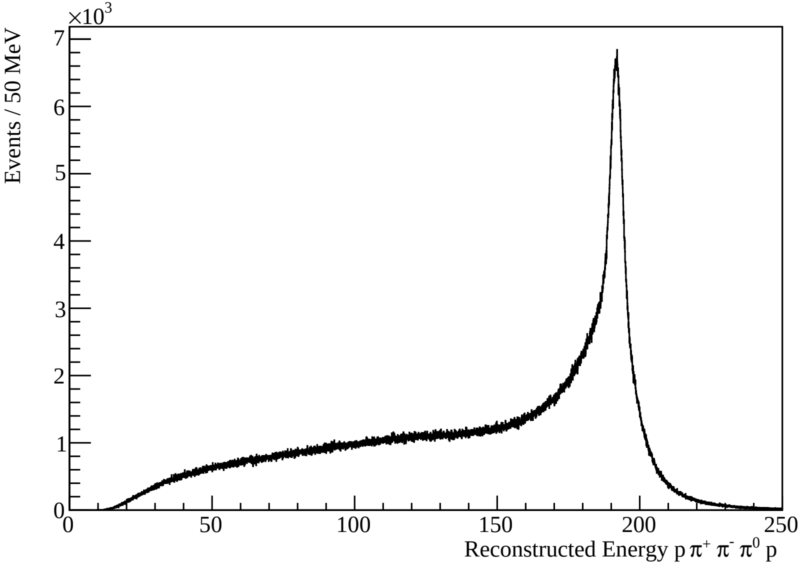
Event selection



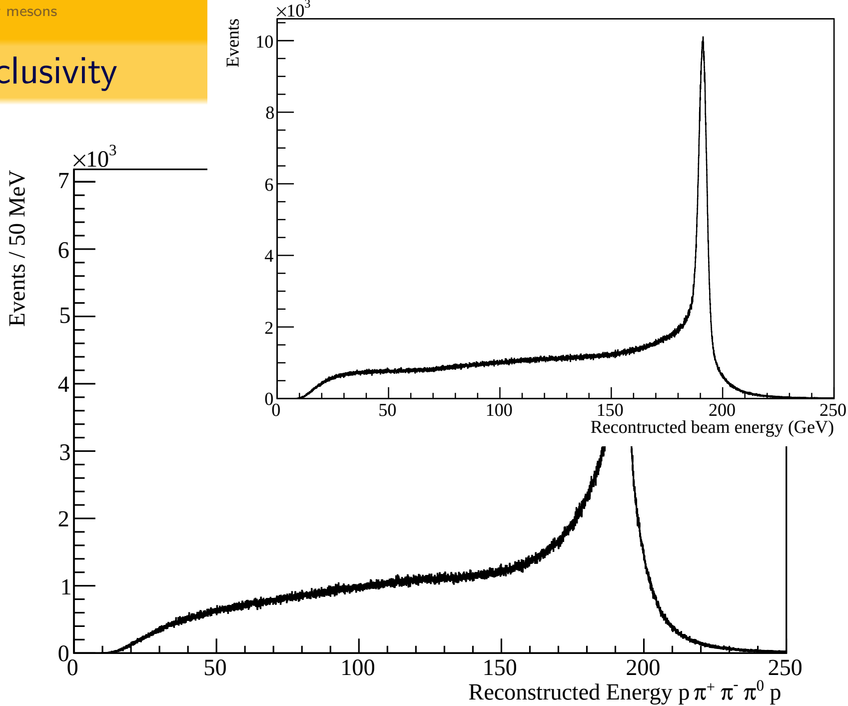
Event selection



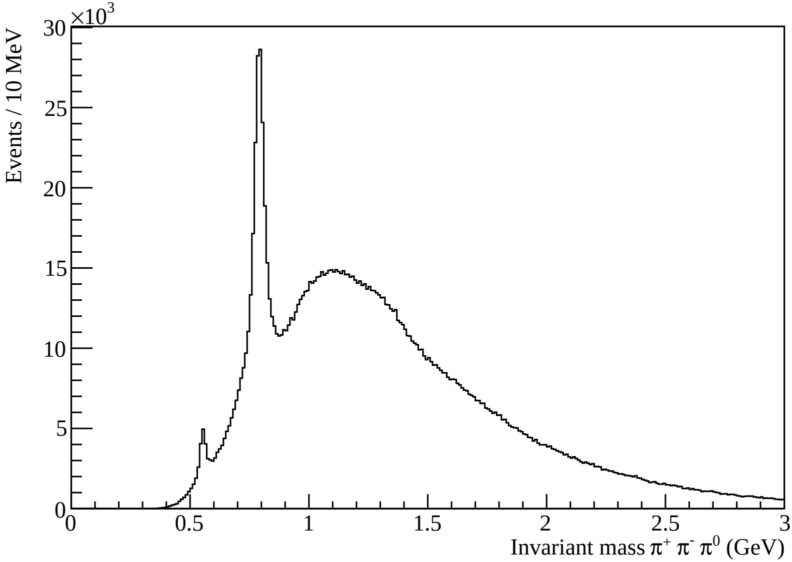
Exclusivity



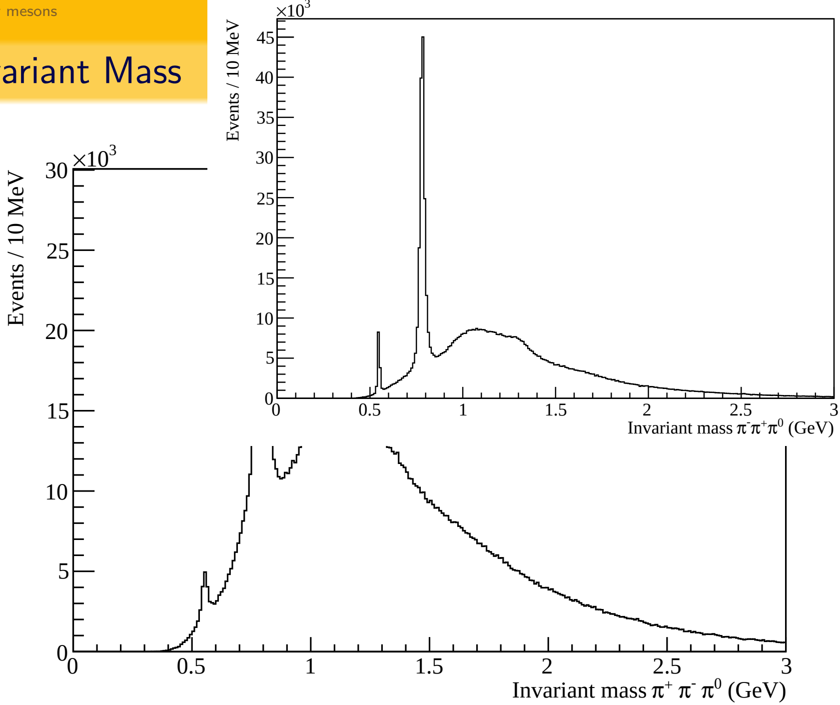
Exclusivity



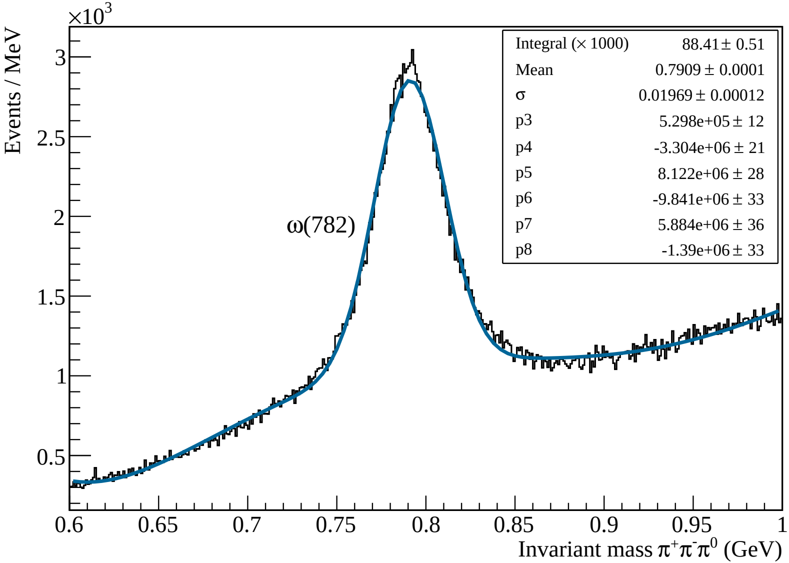
Invariant Mass



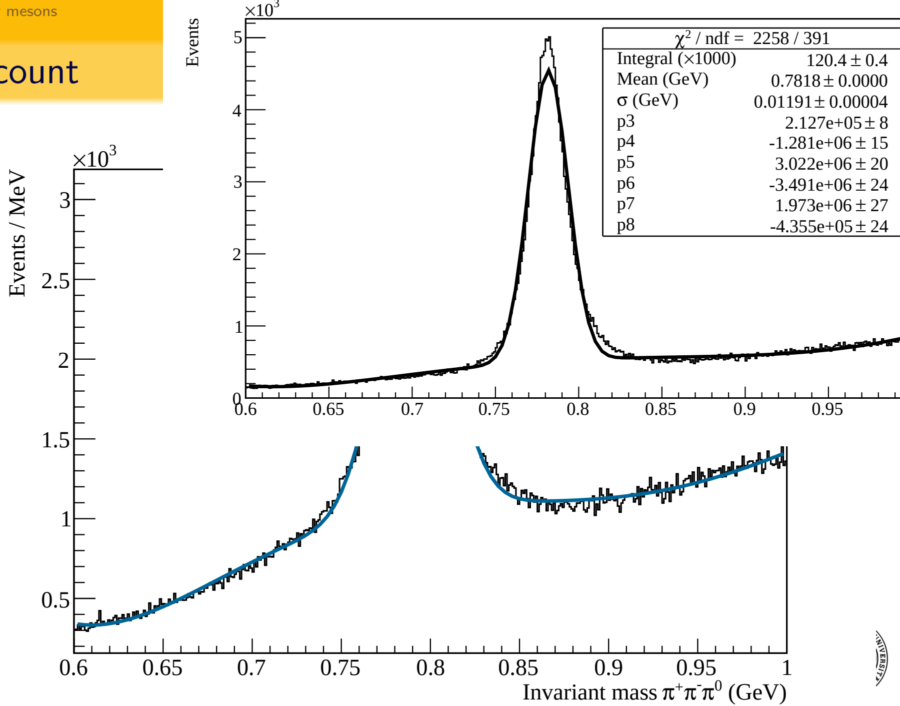
Invariant Mass



ω count


×10^3
Events / MeV
3
2.5
2
1.5
1
0.5
ω(782)
Integral (× 1000) 88.41 ± 0.51
Mean 0.7909 ± 0.0001
σ 0.01969 ± 0.00012
p3 5.298e+05 ± 12
p4 -3.304e+06 ± 21
p5 8.122e+06 ± 28
p6 -9.841e+06 ± 33
p7 5.884e+06 ± 36
p8 -1.39e+06 ± 33
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
Invariant mass π+π-π0 (GeV)

ω count


Events / MeV
×10^3
3
2.5
2
1.5
1
0.5
0.6 0.65 0.7 0.75 0.8 0.85 0.9 0.95 1
Invariant mass π+π-π0 (GeV)
Events
×10^3
5 4 3 2 1 0
0.6 0.65 0.7 0.75 0.8 0.85 0.9 0.95
χ2 / ndf = 2258 / 391
Integral (×1000) 120.4 ± 0.4
Mean (GeV) 0.7818 ± 0.0000
σ (GeV) 0.01191 ± 0.00004
p3 2.127e+05 ± 8
p4 -1.281e+06 ± 15
p5 3.022e+06 ± 20
p6 -3.491e+06 ± 24
p7 1.973e+06 ± 27
p8 -4.355e+05 ± 24